Tense, Aspect and the Cognitive Representation of Time

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ABSTRACT

This paper explores the relationships between a computational theory of temporal representation (as developed by James Allen) and a formal linguistic theory of tense (as developed by Norbert Hornstein) and aspect. It aims to provide explicit answers to four fundamental questions: (1) what is the computational justification for the primitives of a linguistic theory; (2) what is the computational explanation of the formal grammatical constraints; (3) what are the processing constraints imposed on the learnability and markedness of these theoretical constructs; and (4) what are the constraints that a linguistic theory imposes on representations. We show that one can effectively exploit the interface between the language faculty and the cognitive faculties by using linguistic constraints to determine restrictions on the cognitive representations and *vice versa*.

Three main results are obtained: (1) We derive an explanation of an observed grammatical constraint on tense -- the Linear Order Constraint -- from the **information monotonicity property** of the constraint propagation algorithm of Allen's temporal system; (2) We formulate a principle of markedness for the basic tense structures based on the computational efficiency of the temporal representations; and (3) We show Allen's interval-based temporal system is not arbitrary, but it can be used to explain independently motivated linguistic constraints on tense and aspect interpretations.

We also claim that the methodology of research developed in this study -- "cross-level" investigation of independently motivated formal grammatical theory and computational models -- is a powerful paradigm with which to attack representational problems in basic cognitive domains, e.g., space, time, causality, etc.

1. Objectives and Main Results

One major effort in modern linguistics is to limit the class of possible grammars to those that are psychologically real. A grammar is psychologically real if it is (a) **realizable** - possessing a computational model that can reproduce certain psychological resource complexity measures, and (b) **learnable** - capable of being acquired (at least, in principle) despite the poor quality of input linguistic data. A shift of emphasis from the pure characterization problem of grammar to the realization and learnability problems naturally brings linguistics closer to AI work in natural language understanding concerned with computational models of language use and language acquisition. Computational study is in principle complementary to more formal and abstract grammatical theory. Each should contribute to the other.

The purpose of this paper is to work out an example of how formal grammatical theory and computational models can effectively constrain each other's representations. In particular, I seek to explore four fundamental issues:

1. How is the choice of primitive structures in grammatical theory to be justified?
2. What is the explanation of the rules and constraints that have to be stipulated at the grammatical level?
3. How are these knowledge structures acquired?
4. What are the theoretical constraints imposed by the grammar on the representational scheme of the computation theory?

What I hope to show is that structures and principles that have to be *stipulated* at the grammatical level fall out naturally as consequences of the properties of the algorithms and representations of the underlying computational model. In so doing, I will also restrict the class of *plausible* computational models to those that can explain or incorporate the constraints imposed by the formal grammatical theory.

There are a number of requirements that must be met in order for such "cross-level" study to succeed. First, there is a sizable collection of facts and data from the target domain to be explained. Second, there is independent motivation for the theory of grammar -- it is empirically adequate. And, third, the computational model is also independently motivated by being sufficiently expressive and computationally efficient.

With these considerations, I have chosen two domains: (1) tense and (2) aspect. Tense concerns the chronological ordering of situations with respect to some reference moment, usually the moment of speech. Aspect is the study of situation types and perspectives from which a particular situation can be viewed or evaluated (cf. Comrie76) The point of departure of this study is two papers: (1) for the theory of tense, Hornstein's "Towards a theory of Tense" (Hornstein77) and (2) for the cognitive theory of time, James Allen's "Towards a General Theory of Action and

Time" (Allen84).

In the following, I shall list the main results of this study:

1. A better theory of tense with revised primitive tense structures and constraints.

2. We derive an explanation of Hornstein's Linear Order Constraint, an observed formal constraint on linguistic tense, from properties of the constraint propagation algorithm of Allen's temporal system. This shows this formal grammatical constraint need not be learned at all. We also show that the rule of R-permanence follows from the hypothesis that *only the matrix clause and the subcategorizable SCOMP or VCOMP can introduce distinct S and R points*. Finally, we prove that certain boundedness condition on the flow of information of a processing system leads directly to the locality property of a constraint on sequences of tense.

3. A principle of markedness for tense structures based on the computational efficiency of the temporal representation. The principle predicts that (1) of the six basic tenses in English, future perfect is the only marked tense, and (2) the notion of a distant future tense, just like the simple future, is also unmarked.

4. A better account of the state/event/process distinction based on Allen's interval-based temporal logic and the idea that the progressive aspect specifies the perspective from which the truth of a situation is evaluated.

5. An account of theoretical constraints on the representation of time at the computational level, e.g., three distinct time points are necessary to characterize an elementary tensed sentence, and the distinction between instantaneous and non-instantaneous time intervals.

2. Tense

We begin by first outlining Hornstein's theory of tense. In section 2.1, we describe the primitives and constraints on tense of his theory. In sections 2.2 and 2.3, we show how the primitives and constraints can be derived from computational considerations.

2.1 Revisions to Hornstein's Theory of Tense

Hornstein develops a theory of tense within the Reichenbachian framework which postulates three theoretical entities: S (the moment of speech), R (a reference point), and E (the moment of event). The key idea is that certain linear orderings of the three time points get grammaticalized into the six basic tenses of English.[1] The following is the list of *basic* tense structures:

1. SIMPLE PAST	E,R_S
2. PAST PERFECT	E_R_S
3. SIMPLE PRESENT	S,R,E
4. PRESENT PERFECT	E_S,R
5. SIMPLE FUTURE	S_R,E
6. FUTURE PERFECT	S_E_R

The notation here demands some explanation. The underscore symbol "_" is interpreted as the "less-than" relation among time points whereas the comma symbol "," stands for the "less-than-or-equal-to" relation. As an illustration, the present perfect tense denotes a situation in which the moment of speech is either cotemporaneous or precedes the reference point, while the moment of event is strictly before the other two moments. Note that Hornstein also uses the term "association" to refer to the comma symbol ",".

Given the basic tense structure for a simple tensed sentence, the interpretation of the sentence that arises from the interaction of tense and time adverbs is represented by the modification of the position of the R or E points to form a new tense structure which we call a *derived tense structure*. In two papers (Hornstein77 & Hornstein81), Hornstein proposes three formal constraints that limit the class of derived tense structures that can be generated from the basic tense structures in such a way as to capture the acceptability of sentences containing temporal adverbs (e.g., now, yesterday, tomorrow), temporal connectives (e.g., when, before, after), and indirect speech. In the rest of this section, I shall examine the adequacy of these constraints.

2.1.1 Linear Order Constraint

The Linear Order Constraint (LOC) states that (p.523-4):

(1) The linear order of a derived tense structure must be the same as the linear order of the basic structure.
(2) No new association is produced in the derived tense structure.

LOC is stipulated to account for examples consisting of a single temporal adverb such as (4a) and those with two time adverbs such as (32).[2]

4a. John came home i. *now, at this very moment
ii. yesterday
iii. *tomorrow

32 a. John left a week ago [from] yesterday.
b. [From] Yesterday, John left a week ago.
c. *A week ago, John left [from] yesterday.

The basic tense structure for 4(ai) is:

E,R_S (simple past: *John came home*)

Now modifies E or R so that they become cotemporaneous with the moment of speech S with the derived tense structure as

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[1] Hornstein actually listed nine basic tenses, but I think the progressive belongs to the province of aspect rather than tense.

[2] The numberings are Hornstein's.

follows:

```
     E,R,S        (BAD: violates LOC since new
                   association is produced)
```

On the other hand, 4(aii) is acceptable because the modifier *yesterday* leaves the tense structure unchanged:

```
            yesterday
     E,R__S    →     E,R__S  (OK: does not
                              violate LOC)
```

The crucial example, however, is 5(c):[3]

```
5c. John has come home i. ?right now
                      ii. *tomorrow
                     iii. yesterday.
```

LOC predicts (wrongly) that 5cii is good and 5ciii bad.[4] But LOC gives the wrong prediction only on the assumption that the basic tense structures are correct. To account for 5c, I propose to save the LOC and change the following SRE association with the present perfect:

PRESENT PERFECT   E__R,S

With the modified basic tense structure for present perfect, LOC will give the correct analysis. 5cii is bad because:

```
                tomorrow
     E__R,S   → E__S__R    (linear order
                            violated)
```

5ciii is acceptable since:

```
                yesterday
     E__R,S   → E__R__S
```

(OK: no new linear order and no new comma)

The question that naturally arises at this point is: Why does Hornstein not choose my proposed SRE structure for the present perfect? The answer, I believe, will become apparent when we examine Hornstein's second constraint.

2.1.2 Rule for Temporal Connectives

The rule for temporal connectives (RTC) states that (p.539-40):

For a sentence of the form P_1-conn-P_2, where "conn" is a temporal connective such as "when", "before", "after" etc., line up the S points of P_1 and P_2, that is, write the tense structure of P_1 and P_2, lining up the S points. Move R_2 to under R_1, placing E_2 accordingly to preserve LOC on the basic tense structure.

It can be easily seen that my proposed tense structure for present perfect does not work with RTC since it produces the wrong predictions for the following two sentences:

[1] *John came when we have arrived.
[2] John comes when we have arrived.

For [1] the new analysis is:

```
     E,R__S  → E,R__S
         |         |
     E__R,S    E__R__S
```

which does not violate the RTC and hence predicts (wrongly) that [1] is acceptable. Similarly, for [2], the new analysis is:

```
       S,R,E   →    S,R,E     (violates RTC)
         |            |
    E__R,S        E__S,R
```

which predicts (wrongly) that [2] is bad.

This may explain why Hornstein decides to use E__S,R for the present perfect because it can account for [1] and [2] with no difficulty. However, I suggest that the correct move should be to abandon RTC which has an asymmetrical property, i.e., it matters whether P_1 or P_2 is put on top, and does not have an obvious semantic explanation. (See Hornstein's footnote 20, p.543). My second proposal is then to replace RTC with a Rule of R-permanence (RP) stating that:

(RP): Both the S and R points of P_1 and P_2 must be *aligned* without any manipulation of the tense structure for P_2.

Thus sentence [3]:

[3] John came when we had arrived.

is acceptable because its tense structure does not violate RP:

```
     E,R__S      (OK: S and R points are
    E__R__S       already aligned)
```

Now, let us reconsider sentences [1] and [2]. Sentence [1] is not acceptable under RP and the new tense structure for present perfect since:

```
    E,R__S       (violates RP: the two R's
    E__R,S        are not aligned)
```

Sentence [2] is still a problem. Here I shall make my third proposal, namely, that the simple present admits *two* basic tense structures:

SIMPLE PRESENT   S,R,E and E,R,S

Given this modification, sentence [2] will now be acceptable since:

```
     E,R,S       (S and R points are aligned)
    E__R,S
```

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[3] See footnote 7 and 11 of Hornstein's paper.

[4] There may be doubts as regards the acceptability of 5ciii. An equivalent form of 5ciii is acceptable is Danish (Jespersen65, p.271). Also, in French, the present perfect can be used for a situation that held not more than 24 hours before the present moment (Comrie76, p.81).

To examine the adequacy of RP, let us look at more examples:

```
[4] John has come when i.   *we arrived
                       ii.  *we had arrived
                       iii.  we arrive
                       iv.   we have arrived
                       v.   *we will arrive
```

The corresponding analysis is as follows:

```
[4'] i.  E__R,S         (BAD)
         E,R__S

    ii.  E__R,S         (BAD)
         E__R__S

   iii.  E__R,S         (OK)
         E,R,S

    iv.  E__R,S         (OK)
         E__R,S

     v.  E__R,S         (BAD)
            S__R,E
```

We can see that the proposed theory correctly predicts all of the five cases. There is, however, an apparent counter-example to RP which, unlike RTC, is symmetrical, i.e., it does not matter which of the P_i's is put on the top. Consider the following two sentences:

```
[5] i.  John will come when we arrive.
    ii. *John arrives when we will come.
```

RP predicts both 5i and 5ii will be unacceptable, but 5i seems to be good. It is examples like 5i and 5ii, I believe, that lead Hornstein to propose the asymmetrical rule RTC. But I think the data are misleading because it seems to be an idiosyncrasy of English grammar that 5i is acceptable. In French, we have to say an equivalent of "John will come when we will arrive" with the temporal adverbial explicitly marked with the future tense (Jespersen65, p.264). Thus, the acceptability of sentences like 5i can be explained by a principle of Economy of Speech allowing us to omit the future tense of the temporal adverbial if the matrix clause is already marked with the future tense.

2.1.3 Sequences of Tense

Now, we describe the third and final grammatical constraint on sequences of tense. Consider the following sentences:

```
[6] John said a week ago that Mary
            (a) will   leave in 3 days.
            (b) would
```

In the (a) sentence, the temporal interpretation of the embedded sentence is evaluated with respect to the moment of speech. Thus, for instance, [6a] means that Mary's leaving is 3 days after present moment of speech. On the other hand, the (b) sentence has the temporal interpretation of the embedded sentence evaluated with respect to the interpretation of the matrix clause, i.e., [6b] means that Mary's leaving is 4 days before the moment of speech.

To account for the sequence of tense in reported speech, Hornstein proposes the following rule:

(SOT): For a sentence of the form "P_1 that P_2", assign S_2 with E_1.

In general, for an n-level embedded sentence, SOT states that: assign S_n with E_{n-1} (Hornstein81, p.140). With the SOT rule, [6a] and [6b] will be analyzed as follows:

```
[6a'] a week ago
          |
          E1,R1__S1
                    S2__R2,E2       ==> E2 is 3 days
                        |               after S1
                    in three days

[6b'] a week ago
          |
          E1,R1__S1
          |
          S2__R2,E2                 ==> E2 is 4 days
              |                         before S1
          in three days
```

The local property of SOT, i.e., linking occurs only between nth and (n-1)th level, has a nice consequence: it explains why a third level nested sentence like [7]:

```
[7] John said a week ago                   (a)
    that Harry would believe in 3 days     (b)
    that Mary
     (i) will    leave for London in 2 days (c)
     (ii) would
```

has only two temporal readings: (1) in 7(ci), Mary's leaving is two days after the moment of speech, and (2) in 7(cii), Mary's leaving is two days before the moment of speech. In particular, there is not a temporal reading corresponding to the situation in which Mary's leaving is five days before the moment of speech. We would obtain the third reading if SOT allowed non-local linking, e.g., assigned S_3 with E_1.

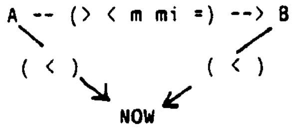
2.2 Explanations of the Formal Constraints

In the previous section, we have examined three formal constraints on the derivation of complex tense structures from the basic tense structures: (1) LOC, (2) RP, and (3) SOT. Now, I want to show how the LOC falls out naturally from the computational properties of a temporal reasoning system along the line suggested by Allen (Allen84, Allen83), and also how the RP and SOT constraints have intuitive computational motivation.

The basis of Allen's computational system is a temporal logic based on intervals instead of time points. The temporal logic consists of seven basic relations and their inverses (Allen84, p.129, figure 1):

Relation	symbol	symbol for inverse	meaning
X before Y	<	>	XXX YYY
X equal Y	=	=	XXX YYY
X meets Y	m	mi	XXXYYY
X overlaps Y	o	oi	XXX YYY
X during Y	d	di	XXX YYYYY
X starts Y	s	si	XXX YYYY
X finishes Y	f	fi	XXX YYYY

The reasoning scheme is a form of constraint propagation in a network of event nodes linked by temporal relationships. For instance, the situation as described in the sentence "John arrived when we came" is represented by the network:



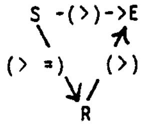
where A = John's arrival and B = Our coming

This network means that both event A and event B are before *now*, the moment of speech, while A can be before, after or simultaneous with B.

When new temporal relationships are added, the system maintains consistency among events by propagating the effects of the new relationships via a *Table of Transitivity Relationships* that tells the system how to deduce the set of admissible relationships between events A and C given the relationships between A and B, and between B and C. Thus, for instance, from the relationships "A during B" and "B < C", the system can deduce "A < C".

One property of the constraint propagation algorithm generally is that further information only causes removal of members from the set of admissible labels, i.e., temporal relationships, between any two old events (Allen83, p.835). No *new* label can be added to the admissible set once it is created. Let us call this property of the constraint propagation algorithm the Delete Label Condition (DLC). DLC can be interpreted as a kind of information monotonicity condition on the temporal representation.

Let us further restrict Allen's temporal logic to instantaneous intervals, i.e., each event corresponds to a single moment of time. The restricted logic has only one primitive relation, ≤, and three other derived relations: <, >, and ≥. There is a straightforward translation of Hornstein's SRE notation into the network representation, namely, replace each comma symbol "," by ≤ (or ≥ with the event symbols reverse their roles) and each underscore symbol "_" by > (or < with similar adjustment on the event symbols). Thus, a tense structure such as: E_R,S can be represented as:



With this representation scheme, we can prove the following theorem:

(T1) DLC → LOC

Proof

Let A and B range over { S, R, E } and A ≠ B. There are five basic types of violations of the LOC:

1. A_B → B_A
2. A_B → A,B
3. A_B → B,A
4. A,B → B,A
5. A,B → B_A

We can see that each of these cases is a violation of the DLC. To spell this out, we have the following operations on the constraint network corresponding to the above violations of the LOC:

1'. A -(<)-> B → A -(>)->B
2'. A -(<)-> B → A -(< =)->B
3'. A -(<)-> B → A -(> =)->B
4'. A -(< =)-> B → A -(> =)->B
5'. A -(< =)-> B → A -(>)->B

In each of these cases, the operation involves the addition of new members to the admissible set. This is ruled out by DLC. Thus, we have the result that if LOC is violated, then DLC is violated. In other words, DLC → LOC.[5] ⊣

The second constraint to be accounted for is the RP which effectively states that (a) the S points of the matrix clause and the temporal adverbial must be identical, and (b) the R points of the matrix clause and the temporal adverbial must be identical. One hypothesis for this rule is that:

(H1) Only the matrix clause introduces distinct S and R points.

In other words, the non-subcategorizable temporal adjuncts do not add new S and R points.

H1 has to be modified slightly to take the case of embedded sentence into account, namely,

(Revised RP): Only the matrix clause and the subcategorizable SCOMP or VCOMP can introduce distinct S and R points.

where SCOMP and VCOMP stand for sentential complement and

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[5] The converse of this theorem is not true.

verbal complement respectively. The interesting point is that both the revised RP and the locality property of SOT can be easily implemented in processing systems which have certain *boundedness* constraint on the phrase structure rules (e.g., information cannot move across more than one bounding node). To illustrate this, let us consider the following tense interpretation rules embedded in the phrase structure rules of the Lexical-Functional Grammar:

```
    S    → NP VP
 (↓ S-POINT) = NOW
    VP   → V (NP) (ADVP) (S')
              (↓ S-POINT) =
             {(↑ E-POINT) if (↓ tense) = PAST
             {NOW           otherwise
    ADVP  → Adv S
    S'   → COMP S
    Adv   → when
         (↑ T-REL) = { <,>,=,m,mi }
            before
         (↑ T-REL) = { > }
```

The S rule introduces a new S point and sets its value to *now*. The VP rule has two effects: (1) it does not introduce new S or R points for the temporal adverbial phrase, thus implicitly incorporating the revised RP rule, and (2) it looks at the tense of the embedded sentential complement, setting the value of its S point to that of the E point of the higher clause if the tense is *past*, and to *now*, otherwise. Thus, in this way, the second effect accomplishes what the SOT rule demands.

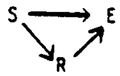
2.3 Implications for Learning

If the revisions to Hornstein's theory of tense are correct, the natural question to be asked is: How do speakers attain such knowledge? This question has two parts: (1) How do speakers acquire the formal constraints on SRE derivation? and (2) How do speakers learn to associate the appropriate SRE structures with the basic tenses of the language?

Let us consider the first sub-question. In the case of LOC, we have a neat answer -- the constraint need NOT be learned at all! We have shown that LOC falls out naturally as a consequence of the architecture and processing algorithm of the computational system. As regards the constraint RP, the learner has to acquire something similar to H1. But H1 is a fairly simple hypothesis that does not seem to require induction on extensive linguistic data. Finally, as we have shown in the previous section, the boundedness of the flow of information of a processing system leads directly to the locality property of the SOT. The particular linking of S and E points as stipulated by the SOT, however, is a parameter of the Universal Grammar that has to be fixed.

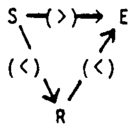
What about the second sub-question? How do speakers learn to pair SRE configurations with the basic tenses? There are 24 possible SRE configurations seven of which get grammaticalized. Here I want to propose a principle of markedness of SRE structures that has a natural computational motivation.

Let us recall our restrictive temporal logic of instantaneous interval with one primitive relation, ≤, and three derived relations: <, >, and ≥. Represent a SRE configuration as follows:

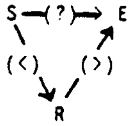


The admissible labels are among { <, <=, >, >= }. So there are altogether 64 possible configurations that can be classified into three types:

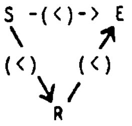
(1) Inconsistent labelings (16), e.g.,



(2) Labelings that do not constrain the SE link given the labelings of SR and RE (32), e.g.:



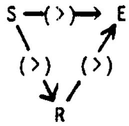
(3) Labelings that are consistent and the SE link is constrained by the SR and RE link (16), e.g.,

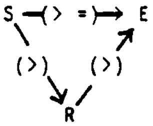


If we assume that labelings of the third type correspond to the unmarked SRE configurations, the following division of unmarked and marked configurations is obtained:

UNMARKED		MARKED	
E__R__S	PAST PERFECT	E__S__R	
E.R__S	SIMPLE PAST	E.S__R	
E__R.S	PRESENT PERFECT	E__S.R	
E.R.S	SIMPLE PRESENT	E.S.R	
S.R.E	SIMPLE PRESENT	S__E__R	FUTURE PERFECT
S.R__E			
S__R.E	SIMPLE FUTURE	S__E.R	
S__R__E		S.E__R	
		S.E.R	
		R__S__E	
		R__S.E	
		R__E__S	
		R__E.S	
		R.E__S	
		R.S__E	
		R.E.S	
		R.S.E	

There are only eight unmarked tense structures corresponding to the sixteen SRE network configurations of type 3 because a tense structure can be interpreted by more than one network representations, e.g., the Past Perfect (E_R_S) has the following two configurations:





The interesting result is that five out of the six basic tenses have unmarked SRE configurations. This agrees largely with our pretheoretical intuition that the SRE configurations that correspond to the basic tenses should be more "unmarked" than other possible SRE configurations. The fit, however, is not exact because the future perfect tense becomes the marked tense in this classification.

Another prediction by this principle of markedness is that both the simple future (S_R,E) and distant future (S_R_E) are unmarked. It would be interesting to find out whether there are languages in which the distant future actually gets grammaticalized.

The final point to be made is about the second type of labelings. There are two other possible ways of grouping the labelings: (1) given SR and SE, those labelings in which RE is constrained, and (2) given SE and RE, those in which SR is constrained. But these types of grouping are less likely because they would yield the simple present tense as a marked tense. Thus, they can be ruled out by relatively few linguistic data.

3. Verb Aspect

In considering the problem of tense, we have restricted ourselves to a subset of Allen's temporal logic, namely, using a temporal structure <T,≤> with linear ordering of time points. To make use of the full power of Allen's temporal logic, we now turn to the problem of verb aspect.

The two main problems of the study of verb aspect are the correct characterization of (1) the three fundamental types of verb predication according to the situation types that they signify -- state, process and event, and (2) the perspectives from which a situation is viewed, or its truth evaluated -- simple or progressive.[6] In the first part of his paper, Allen attempts to provide a formal account of the state/process/event distinction using a temporal logic. However, I believe that his characterization fails to capture well-known patterns of tense implications, and does not make the distinction between situation types and perspective types fundamental to any adequate account of verb aspect. In the next section, I will present some data that any theory of verb aspect must be able to explain.

3.1 Data

3.1.1 Tense Implications

1. Statives rarely take the progressive aspect[7], e.g.,
I know the answer.
*I am knowing the answer.

2. For verb predications denoting processes, the progressive of the verb form entails the perfect form, i.e.,
x is V-ing → x has V-ed.
For instance,
John is walking → John has walked.

3. For verb predications denoting events, the progressive of the verb form entails the negation of the perfect form, i.e.,
x is V-ing → x has not V-ed.
For instance,
John is building a house → John has not built the house.

3.1.2 Sentences containing When

Sentences containing clauses connected by a connective such as "when" have different aspect interpretations depending on the situation types and perspective types involved.

[9] John laughed when Mary drew a circle.
<u>Situation/Perspective type</u>:
X = process/simple; Y = event/simple
<u>Interpretation</u>:
X can be before, after or simultaneous with Y

[10] John was laughing when Mary drew a circle.
<u>Situation/Perspective type</u>:
X = process/progressive; Y = event/simple
<u>Interpretation</u>:
Y occurs during X.

[11] John was angry when Mary drew a circle.
<u>Situation/Perspective type</u>:
X = state/simple; Y = event/simple
<u>Interpretation</u>:
X can be before, after, simultaneous with or during Y.

[12] John was laughing when Mary was drawing a circle.
<u>Situation/Perspective type</u>:
X = process/progressive; Y = event/progressive
<u>Interpretation</u>:
X must be simultaneous with Y.

3.2 Formal Account of the State/Process/Event distinction

Define:

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[6] Some of the better works are: Vendler67, Comrie76, Mourelatos78.

[7] It has often been pointed out that some statives do take the progressive form. E.g., "I am thinking about the exam.", "The doctor is seeing a patient." However, a statistical study has shown that the familiar statives rarely occur with the progressive aspect -- less than 2% of the time (Ota63, section 2.2)

(a) $X \subset Y \leftrightarrow X\ d\ Y \vee X\ s\ Y \vee X\ f\ Y$
(b) $X \subseteq Y \leftrightarrow X \subset Y \vee X \text{ equal } Y$
(c) $\text{mom}(t) \leftrightarrow t$ is an instantaneous interval, i.e., consists of a single moment of time
(d) $\text{per}(t) \leftrightarrow t$ is a non-instantaneous interval[8]

where X and Y are generic symbols denoting state, event or process.

3.2.1 Progressive

(PROG): $\text{OCCUR}(\text{PROG}(v,t)) \leftrightarrow \text{mom}(t) \wedge \neg\, \text{OCCUR}(v,t) \wedge (\exists\, t')(t\ d\ t' \wedge \text{OCCUR}(v,t'))$[9]

The progressive aspect is the evaluation of a situation from an interior *point* t of the situation which has the property that though the sentence is not true at that instantaneous interval, it is true in a non-instantaneous interval t' properly containing t.

3.2.2 State

(S1): $\text{OCCUR}(s,t) \leftrightarrow (\forall\, t')(\text{mom}(t') \wedge t' \subseteq t \rightarrow \text{OCCUR}(s,t'))$

A state verb is true at every instantaneous interval of t. The definition is similar to Allen's H.1 (Allen84, p.130).

The following theorem shows that state verbs do not occur with the progressive aspect.

(S-THEOREM): $^*\text{OCCUR}(\text{PROG}(s,t))$

<u>Proof</u>

$\text{OCCUR}(\text{PROG}(s,t))$
$\leftrightarrow \text{mom}(t) \wedge \neg\, \text{OCCUR}(s,t) \wedge (\exists\, t')(t\ d\ t' \wedge \text{OCCUR}(s,t'))$
$\rightarrow \text{OCCUR}(s,t')$ for some t' containing t
$\rightarrow \text{OCCUR}(s,t)$ (by S1)
$\therefore$ contradiction. $\dashv$

This theorem raises the following question: Why do some statives occur with the progressive? I think there are two answers. First, the verb in question may have a use other than the stative use (e.g. "have" is a stative when it means "possession", and not a stative when it means "experiencing" as in "John is having a good time in Paris.") Second, the English progressive may have a second meaning in addition to that characterized by PROG above. A frequent usage of the progressive is to indicate short duration or temporariness, e.g., in "They are living in Cambridge"/"They live in Cambridge".

3.2.3 Process

A process verb can be true only at an interval larger than a single moment. This property differs crucially from that of the statives.

(P1): $\text{OCCUR}(p,t) \rightarrow \text{per}(t)$
(P2): $\text{OCCUR}(p,t) \rightarrow (\forall\, t')(\text{per}(t') \wedge t' \subseteq t \rightarrow \text{OCCUR}(p,t'))$

The following theorem shows that for a process verb, the progressive verb form entails the perfect form.

(P-THEOREM) $\text{OCCUR}(\text{PROG}(p,t)) \rightarrow (\exists\, t')(\text{per}(t') \wedge t' < t \wedge \text{OCCUR}(p,t'))$

<u>Proof</u>

$\text{OCCUR}(\text{PROG}(p,t))$
$\rightarrow \text{mom}(t) \wedge \neg\, \text{OCCUR}(p,t) \wedge (\exists\, t')(t\ d\ t' \wedge \text{OCCUR}(p,t'))$
$\rightarrow \text{OCCUR}(p,t')$ for some t' such that t d t'
$\rightarrow \exists\, m_1 \in t'.\ m_1 < t$ (since t d t')
$\rightarrow \exists\, m_2 \in t'.\ m_1 < m_2 < t$ (by density of time points)
Let t'' be the interval $[m_1, m_2]$. Then, we have $t'' < t$ and $t'' \subseteq t'$. By (P2), we have $\text{OCCUR}(p,t'')$. That is, p has occurred. $\dashv$.

The characterization of process verb by Allen (his O.2) is less satisfactory because it combines both the notion of progressive aspect (his "OCCURRING") and the process verb into the same axiom. Furthermore, the difference between the predicate "OCCUR" and "OCCURRING" is not adequately explained in his paper.

3.2.4 Event

An event verb shares an important property with a process verb, namely, it can be true only at a non-instantaneous interval.

(E1): $\text{OCCUR}(e,t) \rightarrow \text{per}(t)$
(E2): $\text{OCCUR}(e,t) \rightarrow (\forall\, t')(\text{per}(t') \wedge t' \subseteq t \rightarrow \neg\, \text{OCCUR}(e,t'))$

The following theorem shows that the progressive form of an event verb entails the negation of the perfect form.

(E-THEOREM): $\text{OCCUR}(\text{PROG}(e,t)) \rightarrow \neg(\exists\, t')(\text{per}(t') \wedge t' < t \wedge \text{OCCUR}(e,t'))$

<u>Proof</u>

As in the proof of (P-THEOREM), we can find a non-instantaneous interval t'' such that $t'' < t$ and $t'' \subseteq t'$. But for any such t'', we have $\neg\, \text{OCCUR}(e,t'')$ because of (E2). That is, it cannot be the case that e has occurred. $\dashv$.

Again the crucial property (E1) is not captured by Allen's characterization of events (his O.1).

3.3 Constraint on temporal interpretations involving When

To account for the variety of aspect interpretations as presented in section 3.1.2, I propose the following constraint on

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[8] This section benefits from the insights of Barry Taylor (Taylor77).

[9] A reviewer of this paper points out that the PROG axiom seems to imply that if something is in progress, it must complete. Thus, if Max is drawing a circle, then at some future time, he must have drawn the circle. This inference is clearly false because there is nothing contradictory about "Max was drawing a circle but he never drew it." For instance, Max might suffer a heart attack and died suddenly. This inference problem of the progressive form of a event verb is known as the *imperfective paradox* in the literature. One way out is to deny that Max was really drawing a circle when he died. Rather he was drawing something which *would have been* a circle had he not died. This type of analysis would involve some machinery from Possible World semantics.

situation/perspective type:

(C-ASPECT): Let "dynamic" stand for a process or event.

(a) simple/dynamic → mom(t)
(b) simple/state → per(t)
(c) progressive/dynamic → per(t) $\wedge \subseteq$

Perspective is a way of looking at the situation type. For process or event, the simple aspect treats the situation as an instantaneous interval even though the situation itself may not be instantaneous. For state, the simple aspect retains its duration. The progressive aspect essentially views a process or event from its interior, thus requiring a stance in which the situation is a non-instantaneous interval and the admissible temporal relationship to be the $\subseteq$ relations, i.e., *s, si, f, fi, d, di, equal.*

Let me show graphically how C-ASPECT accounts for the aspect interpretations of sentences [9] to [12].

```
[9'] simple/process WHEN simple/event

Admissible relations:

         <       m        =       mi       >
         X  Y    XY       X       YX       Y  X
                          Y

[10'] progressive/process WHEN simple/event

Admissible relations:

         si      di       fi
         XXX     XXX      XXX
         Y        Y         Y

[11'] simple/state WHEN simple/event

Admissible relations:

         >       mi       si      di       fi
       Y XXX   YXXX       XXX     XXX      XXX
                          Y        Y         Y
         m       <
       XXXY    XXX Y
[12'] prog/process WHEN prog/event

Admissible relations:

         =       f       fi       s       si
         XXX     XXX     XXXX     XXX    XXXX
         YYY    YYYY      YYY     YYYY   YYY
         d       di
          XX     XXXX
         YYYY     YY
```

4. Conclusion

In this paper, I have examined two problems regarding linguistic semantics: tense and aspect. Important relationships between abstract constraints governing linguistic behavior and a computational scheme to reason about temporal relationships are discussed. In particular, I have shown that certain formal constraints, such as the Linear Order Constraint on tense, fall out naturally as a consequence of some computational assumptions. The interesting result is that this formal constraint need not be learned at all.

Another important role of a representation scheme in explaining phenomena that exist on a entirely different -- linguistic -- level is illustrated by the formulation of the C-ASPECT constraint to account for interpretations of sentences containing temporal connectives.

The study of linguistic semantics also sheds light on a representation of time by revealing the fundamental distinctions that must be made, e.g., a tensed sentence involves three distinct time points, and the aspectual interpretations require instantaneous/non-instantaneous interval distinction.

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